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HOVERING AND TRANSITION FLIGHT TESTS OF A SUPERSONIC FAN-IN-FUSELAGE VTOL FIGHTER MODEL

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SUMMARY

An investigation of the dynamic stability and control characteristics of a proposed supersonic fan-in-fuselage VTOL fighter configuration in the transition range from hovering to forward flight has been conducted by the use of a remotely controlled 1/10-scale free-flight model. This configuration has three ducted fans (arranged in tandem) buried in the fuselage for vertical take-off and landing. Vanes under the ducted fans deflect the fan exhaust rearward to produce the forward thrust required for the transition to forward flight. In normal forward flight, the lift fans are covered and conventional jet propulsion is used.

It was found that in hovering flight the model had a very unstable lateral oscillation which became harder to control in forward flight but which could be stabilized by the use of artificial damping in roll and sufficient control power. It was also found that the transition from hovering to normal forward flight could not be successfully completed because of a very large nose-up pitching moment which developed with increasing forward speed and which far exceeded the available pitch control. A total amount of power or jet thrust almost equal to that required to drive the lift fans in hovering flight was used for control during some of the tests, but still did not provide adequate trim and control to accomplish the transition. Analysis of unpublished force-test data indicated that the main cause of the large nose-up pitching moment was the interference of the fan exhausts with the free-stream flow which induced large negative pressures on the lower surface of the fuselage beside and behind the fan exits.

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*Title, Unclassified.

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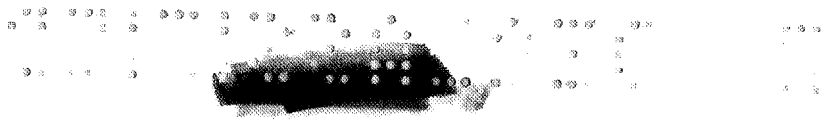

INTRODUCTION

In an effort to obtain an aircraft with VTOL capability and with the cruise performance of advanced supersonic fighters, a type of VTOL aircraft called fan-in-fuselage has been proposed which is intended to have better efficiency in both hovering and forward flight and to present less severe ground erosion problems than pure turbojet aircraft. In the fan-in-fuselage system, the aircraft remains essentially horizontal at all times, and turbojet engines drive lift fans buried in the fuselage for vertical take-off and landing. For propulsion in normal forward flight, the turbojet engines are used in a conventional manner.

An investigation of the dynamic stability and control characteristics of a proposed supersonic fan-in-fuselage VTOL fighter configuration in the transition range from hovering to forward flight has been conducted in the Langley full-scale tunnel by the use of a remotely controlled 1/10-scale free-flight model. The model has three ducted fans (arranged in tandem) buried in the fuselage for vertical take-off and landing. Vanes or louvers under the ducted fans deflect the fan exhaust rearward to provide the forward thrust required to perform the transition to forward flight.

The results were obtained mainly from pilots' observations and from studies of motion-picture records of the flights.

APPARATUS AND TESTS

Model

Photographs of the 1/10-scale model of the proposed supersonic fan-in-fuselage VTOL fighter configuration are shown in figure 1, and a three-view sketch with the more important model dimensions is shown in figure 2. Table I lists the geometric and mass characteristics of the model.

The model represents a configuration which has three lift fans located in tandem in the fuselage; the fans are powered by six small turbojet engines located in a large flat nacelle. The basic model had twin vertical tails located above the fuselage. During this investigation, identical tails were added below the fuselage as shown by the dashed line in figure 2. Each of the three lifting fans in the fuselage had four blades and was driven by a compressed-air jet at the tip of each blade. The three fans were not mechanically interconnected. Compressed air to power the fans was supplied from a common manifold in the model which in turn was supplied from an external source. All

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three fans rotated in the same direction which resulted in gyroscopic moments being introduced by rolling or pitching motions of the model. The gyroscopic moments of the model fans were too high to correctly represent the expected full-scale fan moments; therefore a flywheel, rotating in the opposite direction and driven by an air jet, was installed in the model to permit a correct simulation of the gyroscopic moments.

Vanes or louvers under the three lift fans were used to deflect the fan exhaust rearward and thus provided the forward thrust required to perform the transition from hovering to a forward flight speed where the wing lift would be sufficient to support the weight and allow the lift fans to be shut down. This model was intended to be tested only to this point and no means was provided for actually covering over the fans and switching over to conventional jet propulsion and wing supported flight. The louvers could be deflected from 5° forward to as much as 30° rearward.

For forward flight, the aerodynamic control system consisted of elevons which were operated up and down together for pitch control and differentially for roll control and two conventional rudders located on the vertical tails for yaw control. In hovering and low-speed flight, where the usual control surfaces were not effective, pitch and roll control were provided by compressed-air jet-reaction controls located at the rear of the fuselage for pitch control and in each wing panel for roll control. The pitch jet could be directed either up or down for control whereas both roll-control jets were directed down only and roll control was obtained by increasing the thrust on the roll jet on one side and decreasing the thrust on the other side by means of a valve in the model. Yaw control in hovering flight was provided by vanes located in a fore-and-aft plane beneath the forward and rearward fans as shown in figure 2. The forward and rearward sets of these vanes are deflected differentially and provide a differential side force to produce a yawing moment. For this investigation the control systems were linked together so that both the aerodynamic and jet-reaction controls operated throughout the tests.

The controls were remotely operated by the pilots by means of flicker-type (full-on or off) pneumatic actuators which were controlled by electric solenoids. These actuators were equipped with an integrating trimmer which trimmed the control a small amount in the direction the control was moved each time a control deflection was applied. With actuators of this type, a model becomes accurately trimmed after flying a short time in a given flight condition. The pitch-control actuator on the tail jet and elevons also had a motor-driven trimmer which was operated by the pitch-control pilot with a trim switch so that the pitch control could be rapidly trimmed independently of the flicker-control deflections.

For most of the tests artificial stabilization in roll was provided by a simple rate damper which consisted of an air-driven rate gyroscope as the sensing element to provide a roll-rate signal to a servoactuator which deflected the elevons and roll-jet controls in proportion to the rolling velocity. A pilot-operated override was provided in the gyroscope-operated device so that the pilot could have all the available control at his command.

The control deflections used during the tests were as follows:

	Control	Trim	Total available
Elevons used for pitch, deg	±17	±8	±25
Elevons used for roll (each side), deg	±8	±7	±15
Rudders, deg	±15	±15	±30

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The jet-reaction control and yaw-vane moments used during the first tests were as follows:

	Control	Trim	Total available
Pitch jet, ft-lb	±2.75	±5.5	±8.25
Roll jet, ft-lb	±1.5	0	±1.5
Yaw vanes, ft-lb	±1.0	±0.5	±1.5

These values represented approximately the scaled control moments of the proposed fan-in-fuselage VTOL fighter configuration. During the investigation, the available pitch- and roll-jet moments were increased.

The normal moments of inertia of the model, listed in table I, were somewhat lower than the expected scaled values of the proposed configuration. The moments of inertia about the X, Y, and Z axes were 75, 86, and 88 percent of the scaled values of the full-scale inertia, respectively. For a few hovering tests, the roll inertia was increased to 100 percent of the expected full-scale inertia by adding weight externally on the wing tips.

Tests

The investigation consisted entirely of flight tests to determine the dynamic stability and control characteristics of the model in hovering flight in still air and during the transition between hovering and normal forward flight. It was intended to test this model in the Langley full-scale tunnel to a model flight speed of 50 knots which is the point where it is estimated that a configuration of this type would develop enough aerodynamic lift to be able to shut down the lift fans and convert to normal forward flight. As will be discussed in the following sections, however, the highest velocity reached in this investigation was about 25 knots. These flights were attempts at slow constant-altitude transitions with the fuselage angle of attack held constant at angles of about 0° and 10°. The hovering flight tests were made in the tunnel test section in still air at heights of 10 to 15 feet above the ground to determine the basic stability and controllability of the model out of ground effect. Tests were also made with the rate-damper added to the roll-control system in both the hovering and transition tests.

The test results were obtained both from the pilots' observations and opinions of the behavior of the model and from subsequent study of motion-picture records of the flight tests.

Test Setup and Flight-Test Technique

Figure 3 shows the test setup for the flight tests made in the Langley full-scale tunnel. The sketch shows the pitch pilot, the safety-cable operator, and the thrust controller on a balcony at the side of the test section. An additional operator (also located on the balcony but not shown in fig. 3) was used to control the louvers under the fans. The roll and yaw pilots were located in an enclosure in the lower rear part of the test section. All of these operators were located at the best available vantage points for observing and controlling the particular phase of the motion with which each was concerned. Motion-picture records were obtained with fixed cameras mounted on the side balcony and at the upper rear of the test section.

The air to drive the lifting fans and for the jet controls was supplied to the model through flexible plastic hoses, and the power for the electric solenoids was supplied through wires. These wires and tubes were suspended from overhead and taped to a safety cable of 1/16-inch braided aircraft cable from a point approximately 15 feet above the model down to the model. The safety cable, which was attached to the model near the center of gravity, was used to prevent crashes in the event of a power or control failure or in the event that the pilots lost control of the model. During flight the cable was kept slack so that it would not appreciably influence the motions of the model during the

normal course of the tests. In the final transition tests of this investigation, where the control forces were greatly increased, however, the flight cable became somewhat larger as additional hoses were added to supply the increased quantity of compressed air required and did influence the rolling motions to a noticeable extent. The cable influence was, of course, taken into consideration in analyzing and interpreting the motions of the model.

The test technique is best explained by describing a typical flight. The model hung from the safety cable with the tunnel airspeed at zero, the power was increased until the safety cable became slack and the model was in steady hovering flight. After the hovering test was complete, the tunnel drive motors were turned on and the airspeed began to increase. As the airspeed increased, the attitude of the fuselage was kept at 0° or 10° angle of attack, depending on the test desired, by adjusting the deflection of the vanes under the lifting fans and by adjusting the power to the fans in order to provide the thrust required to balance the lift and drag of the model. As the transition progressed, the controls and power were operated to keep the model as near as possible to the center of the test section. In these particular tests with this model the flights were usually terminated by catching the model on the safety cable after control was lost by either the roll or pitch pilot.

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RESULTS AND DISCUSSION

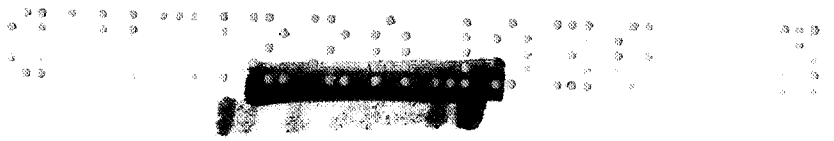
It should be pointed out that the tests and, therefore, the results reported in this paper are not as extensive or as complete as might be expected. Normally, in a dynamic-model flight investigation of this type, an attempt is first made to fly the model in all flight regimes from hovering to forward flight to get an overall feel for its flight characteristics or problem areas before studying any particular flight regime in detail. However, only preliminary tests were made with this model; since the results of these tests showed such unsatisfactory stability and trim characteristics, it was thought unprofitable to proceed with a detailed flight investigation unless some cure for these difficulties could be found. Unpublished data from a force-test investigation of the same configuration showed reasonably good quantitative agreement with these model flight tests; and, since no reasonable cure could be found in the force test investigation, it was felt that there was no point in proceeding with the flight tests of this particular configuration. The characteristics of the model, therefore, were not investigated in take-off and landings or in the presence of the ground, and the hovering tests reported in the following paragraphs were limited to some very brief hovering tests and to the period of hovering flight at the start of each transition attempt.

Hovering Flight

In the relatively limited hovering flight tests of the model, the principal stability characteristic noted was a very unstable rolling oscillation of fairly high frequency. This oscillation involved both bank and lateral displacement. The rolling oscillation made it impossible for the pilots to hover the model for extended periods of time since the slightest disturbance or attempt to maneuver the model resulted in the roll pilot losing control. A check was made to see what effect the gyroscopic moments had as an exciting force on the oscillation by increasing the speed of the flywheel which rotated in the opposite direction from the lifting fans. With the flywheel almost exactly counteracting the gyroscopic effects of the lifting fans, hovering flight could be maintained for longer periods of time but the difference was not great enough to be considered a major effect. For the remainder of the tests, therefore, the flywheel speed was set to give the correct gyroscopic simulation. As pointed out earlier, the roll inertia of the model was 75 percent of the expected scaled values of the proposed configuration. It was not practical to increase this inertia with weights inside the model fuselage since the resulting short moment arm about the X-axis would require a prohibitive amount of weight. However, a few hovering flight tests were made with weights mounted externally on the wing tips to see if increasing the roll inertia to the expected scaled values would appreciably affect the rolling motions. These tests did not show a significant difference so the weights were removed.

The model was then equipped with a roll-rate artificial stabilization system to determine whether a device of this type could stabilize the rolling oscillation. The roll damper greatly improved the flight behavior of the model and allowed steady hovering flight in still air for longer periods of time. To stabilize the rolling motion, however, it was found that the roll-control moment had to be increased to a value of ± 2.2 foot-pounds, or about $1\frac{1}{2}$ times the scaled value of the proposed full-scale configuration to provide an adequate degree of stabilization. With the roll damper installed and with the increased roll control, the model could be flown steadily in roll during hovering flight and could be maneuvered easily to any desired position in the test section.

The motions of the model in pitch during hovering flight were easily controlled by the pitch pilot. Since the stability in pitch was not studied in detail, it is not known whether the model had an unstable pitching oscillation. It was clear, however, that the model did not tend to start a pitching oscillation as quickly as in roll and that, if present, the pitch oscillation had a relatively long period because of the higher pitching moment of inertia of the model. In any event, the pitch pilot experienced no difficulty in controlling the model in



hovering flight with the design control moments. However, no attempt was made to fly the model in gusty air or to maneuver rapidly from one position to another in the test section since the pitch pilot was trying to fly the model steadily to permit study of the more serious rolling motions in the hovering tests.

The yawing motions, as would be expected, seemed about neutrally stable in hovering flight and the directional control, achieved by the differentially deflecting vanes in the lifting fan exhausts, was adequate for steady flight in relatively smooth air.

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Transition Flight

It was found that the transition from hovering to normal forward flight could not be successfully completed. It had been estimated that a forward-flight speed of about 50 knots would be required before enough aerodynamic lift would be developed to allow the conversion from fan-supported to normal wing-supported forward flight. However, the model experienced both lateral and longitudinal problems that usually terminated the flights at a forward-flight velocity of about 12 knots when the scaled control forces were used. In an effort to investigate the magnitude of these problems, the pitch and roll jet-reaction control moments were first doubled and then tripled but successful transitions still could not be made because the pitch-control power was still too low to trim the model throughout the transition range. At this point the flight investigation was terminated because it was felt that the control powers were so high that the tests had no practical significance. The power being supplied to the controls, which were three times the original values, was about equal to the power being supplied to the main lifting fans. The individual lateral and longitudinal characteristics of the model will be discussed in more detail in the following paragraphs.

Lateral characteristics.- All of the transition tests were made with the roll-rate damper installed. As the forward-flight velocity increased, the model became harder to control in roll even with the rate damper operating and with about $1\frac{1}{2}$ times the scaled control forces available. At a velocity of about eight or nine knots, the flights would be terminated by a roll oscillation. It was not known whether the basic stability was worse with forward speed or if the more unsteady motions of the model in forward flight resulted in exciting forces too great for the rate damper to stabilize with the available control moments. In any event, the jet-reaction roll control was increased to about ± 3.0 foot-pounds (double the original control moment) and, under these conditions, the roll control was satisfactory with the rate damper operating for normal flying up to the speeds reached in the tests. Because of occasional violent longitudinal motions, however, the roll

pilot experienced some difficulty occasionally in controlling the model. In the final tests, therefore, the jet-reaction roll control was increased to ±4.5 foot-pounds or about three times the original control power to further improve the rolling motions so that the longitudinal motions of the model could be studied more conveniently. The increased roll-control moment represented a jet force of approximately 13 percent of the model weight.

Although the yaw pilot reported that he was in no danger of losing control of the model at the low forward velocities of these tests, it was difficult at times to hold the model directly in line with the wind. It is not known if the model was directionally unstable at small yaw angles but to be sure that low directional stability was not contributing unduly to the rolling problems, additional vertical-tail area was added below the fuselage. The added tails, shown in figure 2 by the dashed lines, were the same size and shape as the original tails above the fuselage. There was no apparent difference in the rolling motions of the model with the additional tail area but the model was very easy to fly in yaw and only an occasional corrective control was needed during the forward-flight tests.

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Longitudinal characteristics.- The most predominant longitudinal characteristic of this model in forward flight was a large nose-up pitching moment which steadily increased with increasing forward speed. When this nose-up pitching moment reached a value corresponding to the total available pitch control (control plus trim), the model would pitch nose-up out of control and the flight would be terminated. With scale pitch control available (±8.25 foot-pounds), the model reached a forward-flight velocity of about 12 knots. This corresponds to a force at the tail of 7 percent of the model weight. Flights were made at this condition with the fuselage level throughout the flight and also with the fuselage at about 10° angle of attack with no apparent difference in trim characteristics.

In an effort to investigate the magnitude of the nose-up pitching moment with forward velocity with this flying model, the total available pitch control was first doubled and then tripled. Even with tripled control power (±25 foot-pounds of pitch control), however, the model still used up all of the available control and nosed up at approximately 25 knots forward velocity. The velocity at which this occurred was not determined exactly since it was felt that the test had lost practical significance. A control of ±25 foot-pounds represented a force at the tail of about 21 percent of the model weight. This amount of force along with the control-jet force of 13 percent of model weight being used for the roll-control jets gave a total control-jet force of 34 percent of the airplane weight. Since this amount of control force was still not adequate and since the jet thrust required to drive the lift fans of either the proposed full-scale airplane or the model in

hovering flight is about 45 percent of the aircraft weight, it is evident that a control system having a power approaching that of the propulsion system is required. Such a condition seemed so impractical that the flight tests were terminated at this point.

The sources of the large nose-up pitching moments could not be determined in these tests. There are three obvious sources, however, which would tend to produce nose-up moments on a configuration of this type in forward flight. The first is the inlet flow to the lifting fans. A nose-up moment would be expected, as forward velocity is increased, both from inlet-momentum drag acting above the center of gravity and from the resulting forward movement of the center of thrust on the ducted fans. It would not be expected, however, that the inlet-momentum drag would produce much nose-up moment on this model which had a very flat fuselage and, therefore, a short moment arm between the inlet and model center of gravity. The second source would be the deflection of the turning vanes under the lifting fans to produce the required forward thrust. The forward thrust on the turning vanes acting beneath the center of gravity produces a nose-up pitching moment. This contribution to the nose-up pitching moment is probably relatively small because of the small vertical distance between the vanes and the center of gravity. The third source, and probably by far the largest and the one needing the most investigation, is the interference of the fan exhaust with the free-stream flow under the fuselage. Reference 1 and unpublished data have shown that this interference can induce large negative pressures on the lower surface of the fuselage beside and behind the fan exits. In this respect the fan exhausts act just as if they were solid round cylindrical members extending from the lower surface. The free-stream flow speeds up to go around the exhaust and also separates in some regions behind the fan exits. This interference, therefore, results in negative pressures over large areas of the lower surface beside and behind the fans. This lower surface suction can produce large nose-up pitching moments in forward flight.

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CONCLUDING REMARKS

A preliminary investigation of the stability and control characteristics of a supersonic fan-in-fuselage VTOL fighter model showed that in hovering flight the model had a very unstable lateral oscillation which became harder to control in forward flight but which could be stabilized by the use of artificial damping in roll and sufficient control power. It was found that the transition from hovering to normal forward flight could not be successfully completed because of a very large nose-up pitching moment which developed with increasing forward speed and which far exceeded the available pitch control. A total

amount of power or jet thrust almost equal to that required to drive the lift fans in hovering flight was used for control during some of the tests, but still did not provide adequate trim and control to permit the transition to be accomplished. Analysis indicated that the main cause of the large nose-up pitching moment was the interference of the fan exhausts with the free-stream flow which induced large negative pressures on the lower surface of the fuselage beside and behind the fan exits. Unpublished data from a force-test investigation of the same configuration showed reasonably good quantitative agreement with these model flight tests and, since no cure for this difficulty could be found in the force tests, a more detailed flight investigation was not made with this model.

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Langley Field, Va., September 12, 1960.

REFERENCE

1. Williams, John: Some British Research on the Basic Aerodynamics of Powered Lift Systems. Jour. R.A.S., vol. 64, no. 595, July 1960, pp. 413-437.

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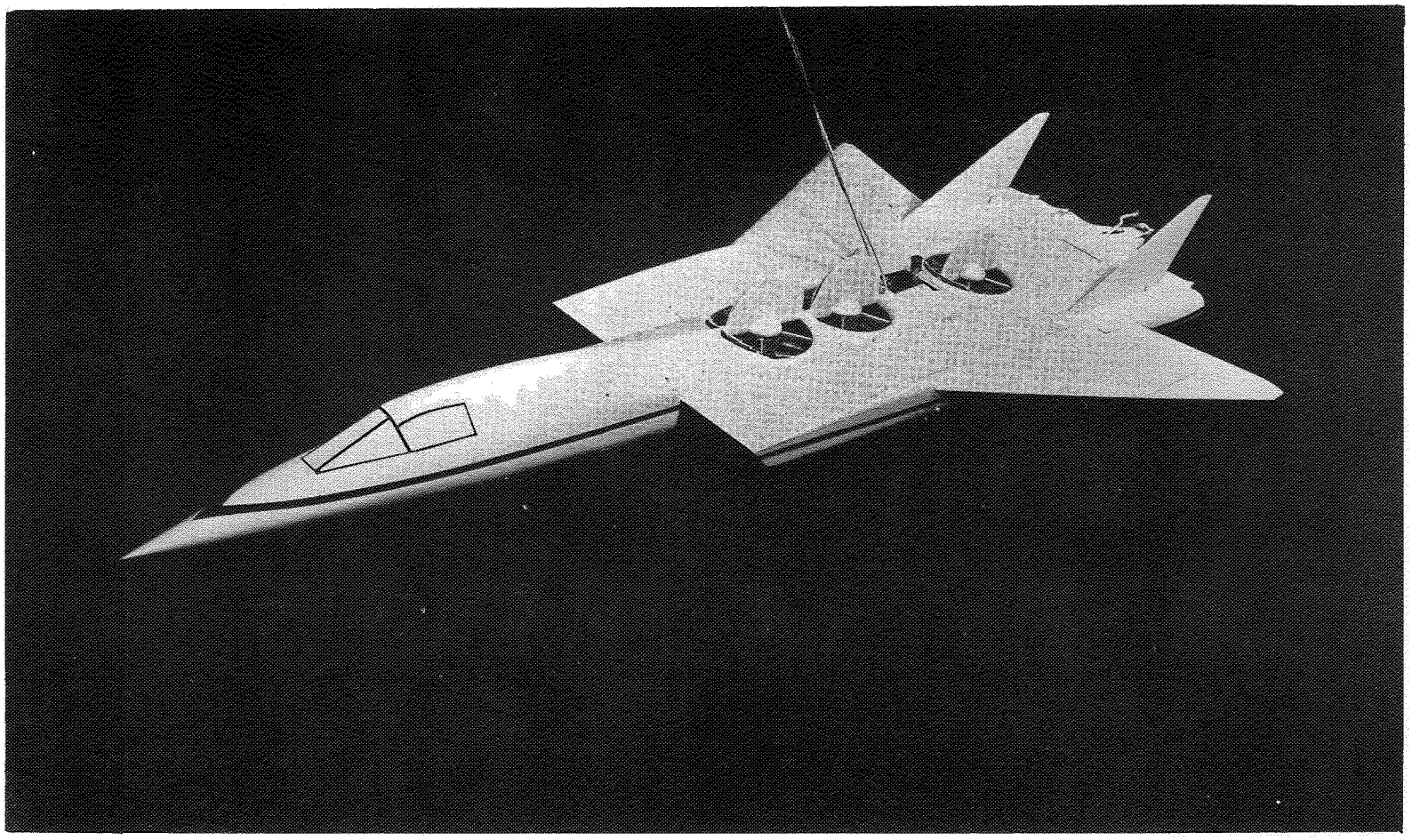
TABLE I

MASS AND GEOMETRIC CHARACTERISTICS OF THE BASIC MODEL

Weight, lb	43.00
Moments of inertia:	
About the X-axis	0.16
About the Y-axis	2.26
About the Z-axis	2.50
Center of gravity, percent mean aerodynamic chord	39.60
Overall length, in.	86.30
Fan diameter, in.	6.50
Wing:	
Span, in.	42.60
Exposed aspect ratio	2.20
Sweepback angle, deg	63.50
Root chord, in.	39.00
Mean aerodynamic chord, in.	26.00
Planform total area, sq in.	864
Incidence, deg	0
Dihedral, deg	0
Leading-edge droop, percent local wing span	10
Total elevon area, sq in.	92
Vertical tails:	
Height (from horizontal reference line), in.	8.25
Exposed aspect ratio	0.96
Taper ratio	0
Sweepback angle, deg	63.50
Root chord, in.	14.88
Area, total exposed, sq in.	98
Rudder area, total, sq in.	10



(a) Three-quarter front view. L-60-1135

Figure 1.- Photographs of basic model.

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(b) Side view.

Figure 1.- Continued.

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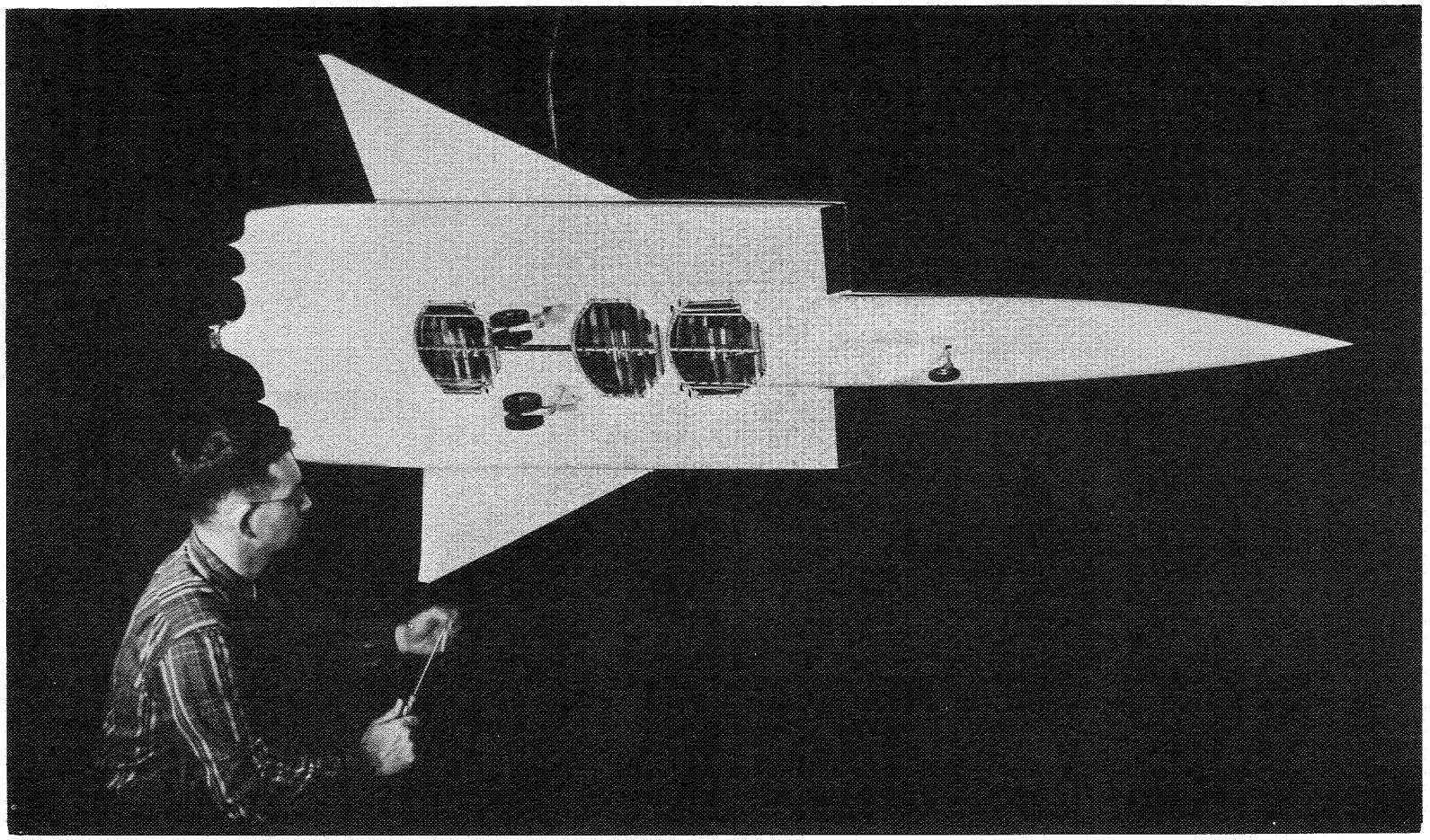

(c) Bottom view showing turning vanes. L-60-1136

Figure 1.- Concluded.

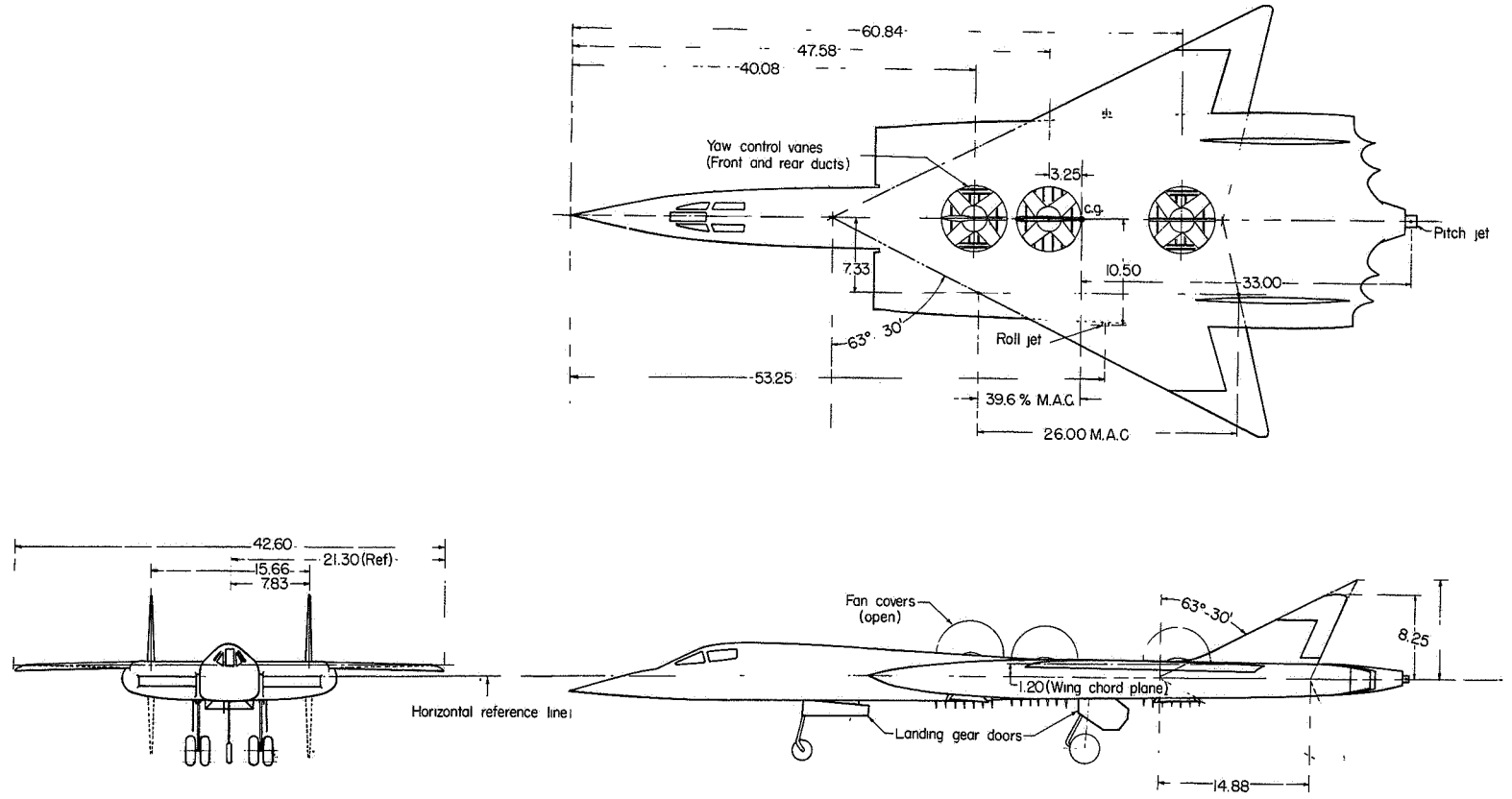

Figure 2.- Three-view sketch of model. All dimensions are in inches.

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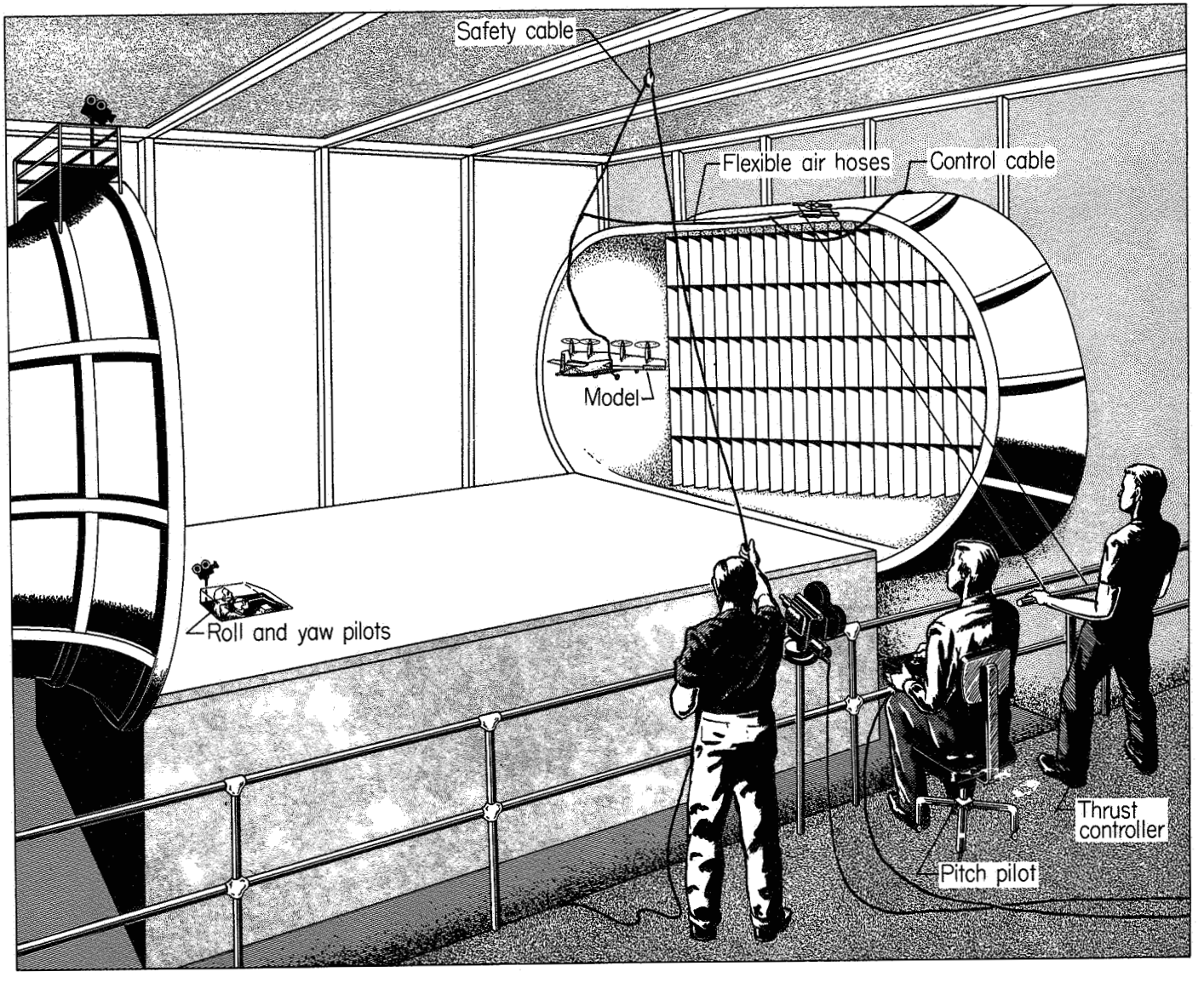

Figure 3.- Typical flight-test setup in the Langley full-scale tunnel.